SMITHSONIAN INSTITUTION

ASTROPHYSICAL OBSERVATORY

OPTICAL SATELLITE-TRACKING PROGRAM

Grant Number NGR 09-015-002

Semiannual Progress Report No. 21
1 July to 31 December 1969

Project Director: Fred L. Whipple

Prepared for

National Aeronautics and Space Administration
Washington, D. C. 20546

Smithsonian Institution
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INTRODUCTION

The most notable event of this half-year period was the completion of the Smithsonian Standard Earth 1969, which represents a culmination of several years of observations of 21 satellites from some 40 observing stations.

During the past 6 months, the Observatory continued its development of a tracking network consisting primarily of lasers augmented by Baker-Nunn cameras. In addition to the laser systems now operating at Mt. Hopkins, Arizona, and near Athens, Greece, three new laser units will be deployed during the first half of calendar year 1970. The first is complete and is being readied for field testing. Construction of the second and third units began in early December 1969.

During this period, SAO coordinated a major international intensive observing campaign of satellites with retroreflectors. This campaign, which began 26 September, is another forerunner to programs SAO hopes to embark on in the future, notably after the launch of the French Peole satellite, expected in mid-August 1970. To this end, the three new laser systems should be operational in the field before that time.

SAO is in the process of reducing the scope of the Satellite-Tracking Program in accord with the substantial budget reduction expected for FY 1971. Also under way is a reexamination of scientific priorities to determine which areas can be retained with the reduced funding.

RESEARCH PROGRAMS

GEODETIC INVESTIGATIONS

Geopotential and Geophysical Studies

Dr. E. M. Gaposchkin and his associates completed a new SAO geopotential model, the Smithsonian Standard Earth 1969. It is based on some 30,000 Baker-Nunn camera observations, 3,000 laser range observations in the dynamic solution, 7,000 simultaneous observations in the geometric solution, and surface-gravity data (averaged over 300 n. mi. squares) provided by Prof. William M. Kaula of UCLA. Tracking data from Mariners 4 and 5 obtained by the Jet Propulsion Laboratory were also used for the model.

The gravity field has been represented by 316 (296 tesseral harmonics and 20 zonal harmonics) parameters, and the coordinates of 40 stations have been determined. The accuracy of the station coordinates is of the order of 10 m or better. The results listed in Tables 1 and 2 were presented jointly by Drs. Gaposchkin and K. Lambeck at the AGU meeting in December 1969.

To check the accuracy of this new geopotential model, we computed ephemerides for the Geos 1 and Geos 2 satellites, using Baker-Nunn camera data and a small number of laser observations. The resulting residuals for 30-day orbital arcs were 2 arcsec for the Baker-Nunn data and 5 m for the laser. The Baker-Nunn residuals are equal to the estimated measuring accuracy of these cameras. We estimate that the ephemeris accuracy for these 30-day arcs is 7 m rms.

One significant characteristic of this new model is that it represents the first instance in which the incorporation of surface measurements in a satellite geopotential has improved satellite-tracking accuracy. This suggests that the lower order coefficients (controlled by the satellite data) more closely reflect the physical characteristics of the earth and are not merely parameters useful for computing satellite orbits.

Table 1. Coordinates for stations

Stn	x	y	z
1021	1.118029	-4.876316	3.942984
1034	-.521702	-4.242049	4.718731
1042	.647515	-5.177924	3.656707
7036	-.828496	-5.657458	2.816812
7037	-.191286	-4.967280	3.983262
7039	2.308239	-4.873597	3.394580
7040	2.465067	-5.534924	1.985510
7045	-1.240479	-4.760229	4.048995
7075	.692028	-4.347059	4.600483
7076	1.384174	-5.905685	1.966533
7818	5.426329	-.229330	3.334608
8015	4.578328	.457966	4.403179
9001	-1.535757	-5.166996	3.401042
9002	5.056125	2.716511	-2.775784
9003	-3.983776	3.743087	-3.275566
9004	5.105588	-.555228	3.769667
9005	-3.946693	3.366299	3.698832
9006	1.018203	5.471103	3.109623
9007	1.942775	-5.804081	-1.796933
9008	3.376893	4.403976	3.136250
9009	2.251829	-5.816919	1.327160
9010	.976291	-5.601398	2.880240
9011	2.280589	-4.914573	-3.355426
9012	-5.466053	-2.404282	2.242171
9021	-1.936782	-5.077704	3.331916
9028	4.903750	3.965201	.963872
9029	5.186461	-3.653856	-.654325
9031	1.693803	-4.112328	-4.556649
9050	1.489753	-4.467478	4.287304
9065	3.923411	.299882	5.002945
9066	4.331310	.567511	4.633093
9074	3.183901	1.421448	5.322772
9077	3.907421	1.602397	4.763890
9080	3.920178	-.134738	5.012708
9091	4.595157	2.039425	3.912650
9113	-2.450011	-4.624421	3.635035
9114	-1.264838	-3.466884	5.185467
9115	3.121280	.592643	5.512701
9117	-6.007402	-1.111859	1.825730

Table 2. Harmonic coefficients of the earth's potential

L	M	C(L, M)	S(L, M)	L	M	C(L, M)	S(L, M)
2	2	2.4129E-06	-1.3642E-06	3	1	1.9699E-06	2.5973E-07
3	2	8.9231E-07	-6.3363E-07	3	3	6.8705E-07	1.4318E-06
4	1	-5.3025E-07	-4.8757E-07	4	2	3.3029E-07	7.0623E-07
4	3	9.8919E-07	-1.5533E-07	4	4	-7.9786E-08	3.3992E-07
5	1	-5.3951E-08	-9.7384E-08	5	2	6.1287E-07	-3.5108E-07
5	3	-4.3065E-07	-8.6451E-08	5	4	-2.6562E-07	8.2063E-08
5	5	1.2580E-07	-5.9745E-07	6	1	-9.8539E-08	3.7621E-08
6	2	5.5167E-08	-3.5159E-07	6	3	2.7889E-08	4.4966E-08
6	4	1.1505E-09	-4.0211E-07	6	5	-2.1163E-07	-5.2251E-07
6	6	8.9429E-08	-7.3988E-08	7	1	2.4173E-07	1.1502E-07
7	2	2.8335E-07	1.5712E-07	7	3	2.0297E-07	-2.3538E-07
7	4	-1.9673E-07	-1.1398E-07	7	5	3.0109E-11	9.8832E-08
7	6	-2.5949E-07	9.9435E-08	7	7	1.5945E-07	-7.3894E-08
8	1	3.0941E-08	2.5757E-08	8	2	4.7289E-08	8.4367E-08
8	3	-5.6950E-08	1.8106E-08	8	4	-1.5241E-07	7.5419E-08
8	5	-5.8931E-08	6.0937E-08	8	6	-5.2118E-08	2.5623E-07
8	7	3.6262E-08	8.8949E-08	8	8	-7.8906E-08	6.7654E-08
9	1	1.3785E-07	-1.4853E-08	9	2	5.8416E-09	-8.2960E-08
9	3	-9.6778E-08	-1.1683E-07	9	4	5.6854E-08	1.1259E-07
9	5	-5.3576E-09	4.0151E-09	9	6	2.4387E-08	2.1701E-07
9	7	-5.7968E-08	-1.3170E-07	9	8	2.3216E-07	5.8646E-08
9	9	-8.3867E-08	9.1835E-08	10	1	1.1319E-07	-1.0160E-07
10	2	-2.9974E-08	-1.0396E-07	10	3	-2.2950E-08	-1.4142E-07
10	4	-4.8796E-08	-4.3769E-08	10	5	-8.0669E-08	-1.4027E-07
10	6	-2.8773E-08	-1.9935E-07	10	7	5.9830E-08	4.0117E-08
10	8	7.5524E-08	-7.8116E-08	10	9	-5.6615E-09	7.1938E-09
10	10	1.2571E-07	-2.4630E-08	11	1	4.6428E-09	2.8458E-08
11	2	4.9202E-08	-9.0751E-08	11	3	-6.5963E-08	-1.3010E-07
11	4	-3.2143E-08	5.3559E-08	11	5	3.2404E-08	1.3070E-07
11	6	3.8437E-08	1.1169E-08	11	7	4.0219E-08	-1.4549E-07
11	8	7.4959E-08	-1.6131E-08	11	9	1.3814E-07	-1.6435E-08
11	10	-1.2068E-07	-1.9216E-08	11	11	1.1872E-07	-3.9782E-08
12	1	-4.6698E-08	-3.0767E-08	12	2	2.6277E-08	7.6358E-08
12	3	6.0026E-08	5.3485E-08	12	4	-4.2331E-08	-2.1396E-08
12	5	2.4246E-08	3.9557E-08	12	6	-2.8914E-08	-8.3671E-09
12	7	9.5064E-09	9.7782E-08	12	8	-5.2238E-09	3.1805E-08
12	9	-1.0817E-07	6.3165E-08	12	10	-1.7965E-08	3.1571E-09
12	11	-4.4853E-08	-4.7141E-08	12	12	-1.8486E-08	-5.8638E-08
13	1	-5.6245E-08	2.7808E-08	13	2	-4.7294E-08	1.6204E-08
13	3	2.5879E-08	-3.0643E-08	13	4	-2.0399E-08	5.4564E-08
13	5	1.0439E-07	-4.3795E-08	13	6	-7.9839E-08	6.3811E-08
13	7	-4.2920E-08	-1.2401E-09	13	8	-4.4909E-08	-1.2785E-08
13	9	1.3703E-08	9.4477E-08	13	10	8.9462E-08	-1.0947E-08
13	11	-3.6319E-08	6.5422E-08	13	12	-1.0036E-09	8.2946E-08
13	13	-7.0289E-08	7.4708E-08	14	1	-2.4725E-08	4.9773E-08
14	2	3.4047E-08	-4.4499E-08	14	3	1.6183E-08	4.4758E-09
14	4	7.4644E-09	-3.6056E-08	14	5	-2.9983E-08	-2.5082E-08
14	6	1.5787E-08	-5.3044E-08	14	7	3.9149E-09	6.6173E-09
14	8	-2.4491E-08	-6.8388E-08	14	9	3.3324E-08	9.9273E-08
14	10	5.9033E-08	-4.3587E-08	14	11	2.6820E-08	-9.8229E-08
14	12	1.3044E-08	-5.7885E-08	14	13	5.1482E-08	4.5429E-08
14	14	-5.1958E-08	-1.2788E-08	15	1	-2.8495E-09	3.8913E-08
15	2	-4.5690E-08	-1.5271E-08	15	3	9.7747E-09	-9.8506E-09
15	4	1.5104E-08	6.7107E-08	15	5	3.1758E-08	6.0088E-09
15	6	6.9508E-08	-1.2555E-07	15	7	1.1985E-07	4.3095E-08
15	8	-9.8362E-08	-3.2429E-08	15	9	2.7448E-08	2.4685E-08
15	10	-2.6596E-08	-4.9782E-09	15	11	-3.4431E-08	1.0945E-07
15	12	1.0919E-08	7.7470E-09	15	13	-3.7315E-08	4.0533E-09
15	14	1.2179E-08	-2.6736E-08	15	15	1.4339E-09	-1.4894E-08
16	1	-2.4497E-08	7.6430E-08	16	2	2.0929E-08	3.0230E-08
16	3	-4.6389E-08	3.4582E-08	16	4	-1.0714E-08	4.2650E-08
16	5	-4.4249E-08	3.0023E-08	16	6	-5.8410E-08	-3.9827E-08
16	7	1.0861E-07	5.4251E-09	16	8	-8.6087E-08	-2.2085E-09
16	9	3.4694E-09	-1.0527E-07	16	10	-2.3419E-08	2.6738E-09
16	11	7.8110E-09	-7.4417E-08	16	12	2.3197E-08	-3.4517E-08
16	13	3.5500E-08	2.0785E-08	16	14	-7.2105E-09	-2.2712E-08
16	15	-3.4147E-08	1.3871E-09	16	16	-3.1106E-08	1.1809E-08
17	12	8.3407E-08	4.2038E-09	17	13	3.2653E-08	5.5308E-10
17	14	-1.6082E-08	2.7350E-08	18	12	1.1779E-08	8.2913E-09
18	13	4.7018E-09	-3.5456E-08	18	14	-2.7573E-08	-4.8356E-08
19	12	6.7247E-08	-8.0048E-09	19	13	3.3101E-08	-6.3092E-08
19	14	-4.0012E-09	-2.3747E-08	20	13	5.8368E-08	3.3334E-08
20	14	1.0908E-08	-1.6086E-08	21	13	3.6582E-09	-1.6320E-08
21	14	5.2016E-08	3.6180E-10	22	14	-8.3277E-09	2.6526E-08

With use of the programs developed for the above work, studies have been started to determine polar motion and GM. These studies plus the determination of earth tides and earth rotations will be continued next year.

The programs for literal algebra, prepared jointly by Dr. Gaposchkin and Mr. J. R. Cherniack, have been successfully used to verify parts of the orbital theories employed in the above analyses.

Mr. Cherniack has also begun a determination of the geopotential by numerically differentiating the laser observations.

Dr. P. A. Mohr has been engaged in measuring movements of the earth's surface. While on a geodetic expedition in Ethiopia, he carried out a geodimeter-theodolite survey. Remeasurement of this survey in a few years will detect the rate of crustal deformation in the region of the African rift valley.

The results of Dr. Mohr's geotectonic expedition to this same country in the spring of 1969 have also been processed and evaluated. Data from both expeditions are being used for investigations of seismic stress fronts, Ethiopian lavas, and crustal behavior.

Dr. L. Sehnal is researching the problems of nongravitational short-periodic perturbations of the orbits of artificial satellites. He has also devoted much of his time to solar radiation pressure and to analytical expressions for the effect of the earth's shadow.

Dr. Lambeck and Mr. A. Girnius have done further work on determining the relationships between the various major datums and the global geocentric system. This study has involved the use of various transformations, including displacement of the datum origin, rotation, and deflection of the vertical and scale factors.

Other studies begun by Drs. Gaposchkin and Lambeck during this period have included laser ranging to the precise measurement of the earth's rotation, polar motion, and solid tides.

Laser System

New data from the ruby-laser system at Mt. Hopkins have been analyzed by Mr. C. G. Lehr and Dr. M. R. Pearlman as part of a continuing study of its limiting range and accuracy.

A method of comparing range measurements from the collocated SAO and NASA lasers on Mt. Hopkins has also been developed. Based on nearly simultaneous observations at the epoch of closest satellite approach, it has yielded the displacement between the two laser systems.

Laser probing of the atmosphere is another topic of research now under way at Mt. Hopkins. Eventually, Dr. Pearlman hopes through such probing to study aerosol and dust layers above the observing site.

Calculations and plans have also been made regarding the installation of an extended-range neodymium-glass laser at the Agassiz Station of the Harvard College Observatory.* A modified version of this system will be used for satellite tracking this spring in a preliminary "shake-down" exercise.

Dr. N. C. Mathur has assisted in making operational on the CDC 6400 computer a ray-tracing program developed by ESSA to study ionospheric effects on radio signals. For this program, ionospheric and tropospheric profiles have been obtained from various agencies. In turn, the program has been used to calculate the corrections to be applied to the delay caused by the atmosphere. The results are applicable to signals from satellites and radio stars. The diurnal, seasonal, and geographic variations of the delay have also been studied.

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*Supported in part by NASA Contract NASW-2014.

International Cooperation

International cooperation in making satellite observations has continued during the past 6 months. Mr. J. Rolff has maintained close contact with international participants in NASA's Geos 2 observing program. Observation reports received from Uppsala, Sweden, from Helsinki, Finland, and from the USSR stations in Riga, Uzhgorod, and Mirny have been checked and transmitted to the Space Data Center at Goddard Space Flight Center (GSFC).

Another of his projects has been the computing of differences between various Atomic and Universal Time scales used in satellite tracking during the last 8 years. The results will facilitate the use of satellite observations.

ATMOSPHERIC INVESTIGATIONS

Atmospheric Investigations

Dr. L. G. Jacchia has continued his work on the construction of models of the thermosphere and lower exosphere for incorporation into the new COSPAR International Reference Atmosphere (CIRA). His models are now complete and will be integrated with the models of the lower regions (from 20 to 110 km) that have been prepared by Cole (U. S.), Groves (U.K.), and Champion (U. S.). The new CIRA should be ready for publication in 1970.

A study by Dr. Jacchia of the diurnal density variation as derived from satellite drag has revealed that the shape of the density curve varies with height and with solar activity. New parameters are being developed to describe these variations as well as the change of the diurnal variation with latitude and seasons.

The solar-activity effect in the temperature of the upper atmosphere has been separated by Dr. Jacchia and Mr. J. W. Slowey into two components that have been related to the disk component and to the active-area component, respectively, of the 10.7-cm solar flux. The change of atmospheric temperature that accompanies a change by one unit in the disk component of the flux is three times as large as that corresponding to the same change in the active-area component. Fortunately, the disk component of the flux is, for all practical purposes, a linear function of the flux averaged over three solar rotations; thus, the use of the latter quantity in place of the disk component appears to be justified.

The three-dimensional spherical model of the upper atmosphere designed by Dr. M. P. Friedman and his associates has been successfully extended to include winds. As a result of a series of studies in upper atmosphere dynamics with this model, his group has found that the winds are directed away from the daytime, high-temperature, high-density side of the earth toward the nighttime, low-temperature, low-density side. Furthermore, the winds have greatest magnitude — about 100 m/sec — near 140-km altitude. This velocity then decreases with increasing altitude, becoming negligible above 400 km. These results will be presented in an SAO Special Report.

Celestial Mechanics

During the last 6 months, Dr. S. E. Hamid has continued his research on second-order general planetary theory in rectangular coordinates through harmonic analysis techniques. The results, already published as SAO Special Report No. 302, were presented at the Albany meeting of the AAS.

In collaboration with Meffroy and Muller, Dr. Hamid has also applied Von Zeipel's method of developing the general planetary theory of the first order in masses. This study will eventually include the effects of long-period inequalities and the higher order of masses.

Planetary perturbations on the moon are now being explored and will be continued into the next year. The increased accuracy of lunar observations requires that these perturbations be recomputed to an accuracy far greater than that of Brown's classical study. To accomplish this, Dr. Hamid has formulated two approaches and intends to include numerical applications.

Another study — the differences among the libratory situations of minor planets and comets — has been successfully completed by Dr. B. G. Marsden. He has concluded that even though there is decisive evidence that comets turn into objects that look like minor planets, these "minor planets" have subsequent lifetimes of not more than a few thousand years. He has also found that the comets that look most like minor planets have in recent centuries been the ones most successful in avoiding Jupiter; the more diffuse comets have frequently passed near Jupiter. Therefore, the comets that had passed near Jupiter had larger perihelion distances not many centuries ago and could have been preserved until then in the frigid outer reaches of the solar system.

Other topics of study by Dr. Marsden have included a program for predicting occultations of stars and radio sources by comets, as well as the use of the computer to perform the algebraic manipulations required in Hori's improvement of the Von Zeipel method.

DATA ACQUISITION

SATELLITE-TRACKING AND DATA-ACQUISITION DEPARTMENT

Operations

SAO coordinated two major tracking efforts in support of the Apollo Space Program during the last half of 1969. USAF Baker-Nunn stations, the Wallops Island, Virginia, radar installation, the Ascension Island tracking station, the U. S. Coast and Geodetic Survey, and numerous professional and amateur observatories around the world participated with the SAO Baker-Nunn stations in support of the Apollo 11 and 12 missions.

During the Apollo 11 mission in July, several successful observations were made. Most major mission events, however, were performed beyond the visibility of ground-based optical stations.

In contrast, visibility during the Apollo 12 mission in November was ideal. The SAO stations in Spain and Brazil obtained a complete photographic record, spanning several hours, of events during and after separation of the spacecraft and S-4B booster. This record includes photographs of the helium, hydrogen, and oxygen fuel dumps from the S-4B rocket (see Plate 1). Several participating agencies in Europe also obtained photographs during the fuel dumps. The primary objective of SAO's Apollo support was achieved during Apollo 12 when the Mt. Hopkins Baker-Nunn camera photographed the first Environmental Control System (ECS) waste-water dump of the mission on 15 November (see Plate 2). Supplementary observations of this event were also made by other participating groups.

In August, on special request from NASA, SAO stations tracked Intelsat III f5 following its failure to achieve synchronous orbit.* Baker-Nunn tracking

*Supported by NASA Contract NAS 10-6834.

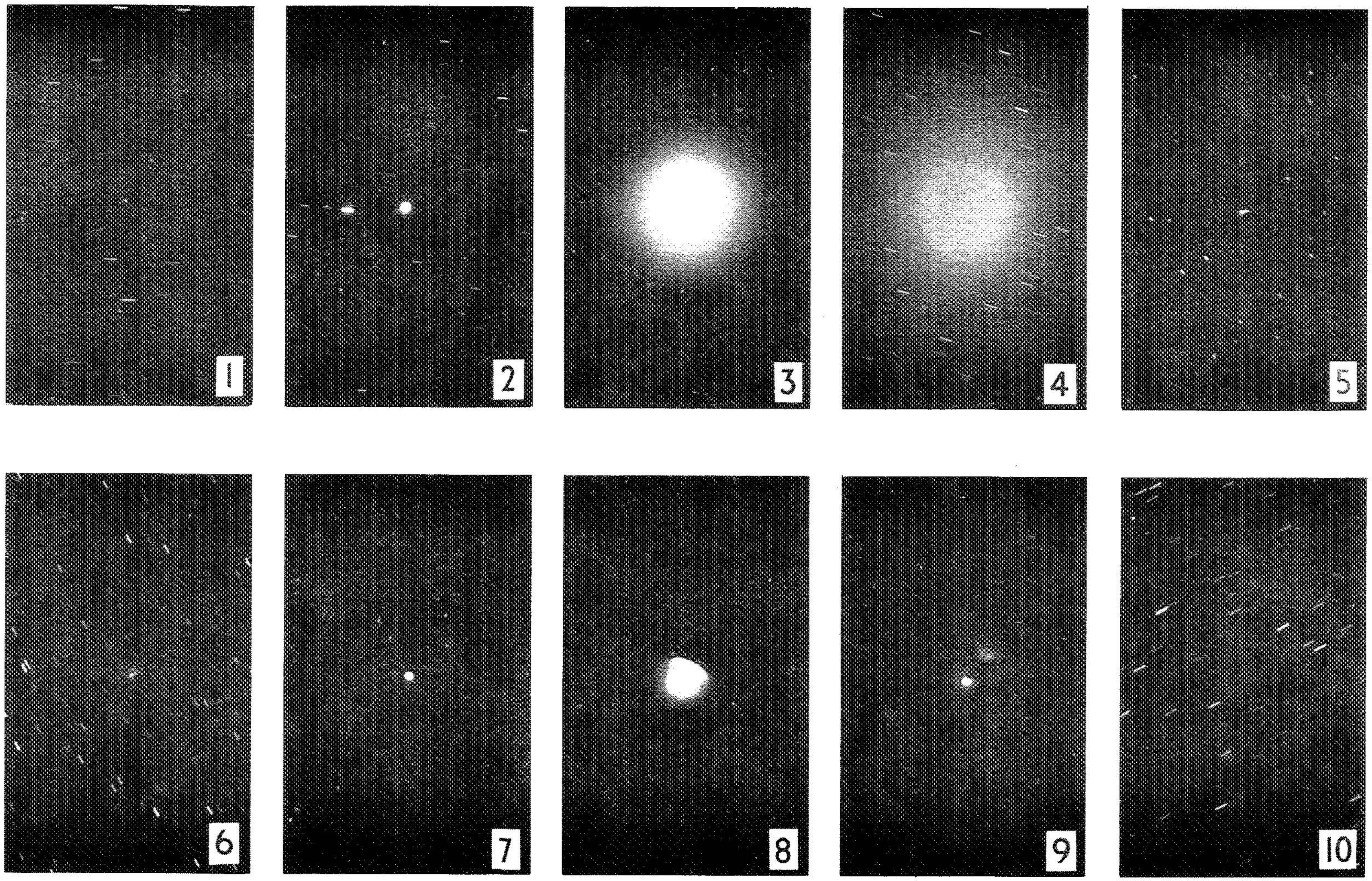

Plate 1. Photographs of Apollo 12 cryogenic release taken 14 November 1969 by the Baker-Nunn camera in San Fernando, Spain. Frame 1 shows the spacecraft, S-4B, and several SLA panels; frames 2-4 were taken during the helium blowdown, and frames 5 and 6 during the beginning of the slingshot maneuver; and the remaining frames document the liquid-helium and liquid-oxygen dumps.

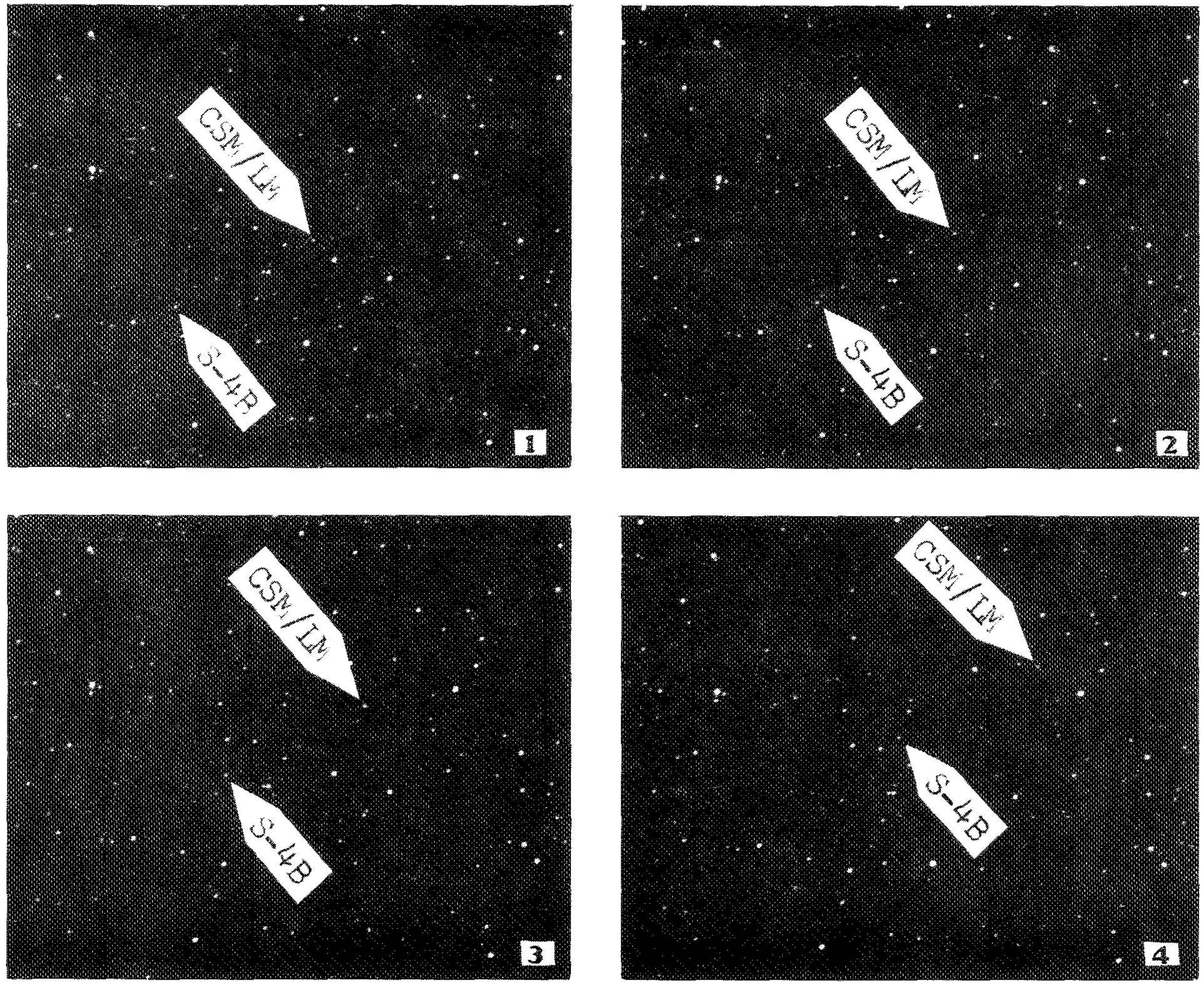

Plate 2. Photograph of the Apollo 12 Environmental Control System waste-water dump taken 15 November 1969 by the Baker-Nunn camera at Mt. Hopkins, Arizona. The Command Service Module/Lunar Module is slightly fainter than the S-4B in frame 1 but brightens perceptibly during the next two frames as a result of the water dump. Following the water dump, the brightness falls off, and by frame 4 the spacecraft is approximately the same brightness as the S-4B.

data were used to determine the number of objects that entered orbit, and the relative positions and orbital parameters of the primary objects.

Reduction of the data taken in support of the Heos 1 barium-cloud experiment in March was completed in September and forwarded to the Max Planck Institute for Physics and Astrophysics in Munich, Germany.

The SAO 1969 Saturation Tracking Program, which was undertaken in cooperation with other space research organizations around the world, commenced on 26 September. The objectives included collection of laser data for geophysical analysis and support of two simultaneous collocation experiments, one with lasers of NASA/GSFC and SAO at Mt. Hopkins, Arizona, and the other with lasers of the French Centre National d'Études Spatiales (CNES) in Haute Provence, France.

During the program, two periods of intensive laser/Baker-Nunn observations of Geos 2 were conducted, the first from 26 September to 31 October 1969, and the second beginning 28 November 1969. In addition, a period of intensive tracking of Geos 1 took place from 10 October to 7 November, as part of a simultaneous program involving the NASA laser at Greenbelt, Maryland, and the Baker-Nunn/laser at Mt. Hopkins, Arizona.

SAO continued its cooperative simultaneous observing program of the Pageos satellite with western European cameras and the U.S. Coast and Geodetic Survey.

The total number of laser returns was lower this period because of relocation of the Greece unit and because of special tasks assigned both units. Only two of the six satellites suitable for laser ranging experiments were employed.

Laser ranging operations on Maui, Hawaii, ceased in July, and the laser transmitter was returned to its owner, the General Electric Company.

During July and August, the Greece laser system was moved to a new, permanent location in Dionysos. The equipment was disassembled, and extensive electronic and mechanical modifications were made to improve operations.

The Mt. Hopkins laser system participated in a special intercomparison experiment with the Goddard mobile laser system.* Preliminary analysis of data shows very favorable results. The ranging accuracies of the two systems appear to be within ~1 m.

Many range return pulses were photographed on an oscilloscope and compared with other oscilloscope photographs from a ground reflector for statistical analyses and for studies of pulse structure. Atmospheric-profile measurements were conducted at the same time.

The Mt. Hopkins Baker-Nunn camera photographed laser-illuminated satellites several times. The Baker-Nunn network was routinely employed in studies of the accuracy of satellite predictions for lasers.

Astronomical Observations

In support of the IAU flare-star observing program, several SAO stations photographed UV Ceti for a 2-week period in December. This support was scheduled to avoid interference with routine tracking operations at the stations.

Operational Statistics

During this period, the two SAO laser systems recorded more than 700 successful range measurements, about half of which were obtained in full daylight with the Mt. Hopkins laser. The Baker-Nunn cameras obtained a total of 11,555 regular, simultaneous, and Geos-flash observations. Table 3 lists all satellites tracked during the period.

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*Supported by NASA Contract NAS 12-2129 Task #11.

Table 3. Satellites tracked from 1 July through 31 December 1969

Tracked on request from NASA

Satellite	Name
1963 53 A	Explorer 19
1965 89 A	Geos 1
1966 56 A	Pageos 1
1967 73 A	OGO 4
1968 2 A	Geos 2
1968 66 A	Explorer 39
1969 51 A	OGO 6
1969 59 A	Apollo 11
1969 59 B	Apollo 11 SIV B
1969 64 A	Intelsat
1969 99 A	Apollo 12
1969 99 B	Apollo 12 SIV B

Tracked for SAO Geodesy and Earth Physics

1959 Alpha 1	Vanguard 2
1960 Iota 2	Echo 1 Rocket
1960 Nu 1	Courier 1B
1961 Alpha Delta 1	Midas 4
1964 64 A	BE-B
1965 32 A	BE-C
1965 78 A	
1965 89 A	Geos 1
1966 56 A	Pageos 1
1967 11 A	D1C
1967 14 A	D1D
1968 2 A	Geos 2
1968 55 A	Explorer 38

Tracked for SAO Atmospheric Investigations

1958 Alpha 1	Explorer 1
1959 Alpha 1	Vanguard 2
1960 Xi 1	Explorer 8
1963 53 A	Explorer 19
1966 44 A	Explorer 32
1968 66 A	Explorer 39
1969 9 A	Isis 1

Engineering Support

Precision Timing and Associated Electronics. Average maximum possible timing uncertainty at the Smithsonian astrophysical observing stations as of 31 December 1969 was ±81 μsec. Sixteen time comparisons with the portable clocks were made at the field stations during this period. Three comparisons between the U. S. Naval Observatory (USNO) and SAO's Cambridge timing facility were made, one using a USNO portable atomic standard. UTC(SAO) was maintained to within ±5 μsec of UTC(USNO).

A timing link was established between the Woomera, Australia, station and the Jet Propulsion Laboratory Moonbounce timing station, also in Woomera. The link allows continuous comparison between the two station clocks, with a resulting improvement of timing accuracy.

Normal maintenance of the EECo timing system and associated electronics was carried out at Cambridge and at all field stations. Major maintenance was required at the Mt. Hopkins, Arizona, and Dodaira, Japan, stations as the result of nearby lightning strikes.

Camera Maintenance and Development. Operating tolerances of the Baker-Nunn camera were kept well within specifications. A transport transmission was exchanged on Comodoro Rivadavia, Argentina, camera. All other maintenance was routine.

The final report on tests of the figure of the Baker-Nunn backup plate was completed and distributed. Data from the study were compared with a computer analysis of the Baker-Nunn optical system at the Perkin Elmer Corporation in Norwalk, Connecticut. The results were published by Perkin Elmer in a modification study report of the Baker-Nunn camera, *Final Study Report on Advancements in Optical and Photographic Technology of the KS-79A Optical Tracking System* (Engineering Report No. 9709), in September 1969.

An SAO-designed and -fabricated mounting for the corrector-cell window was sent to the Hawaii station for photographic testing. Test films were photoreduced at Cambridge. The overlapping portions of a pair of comparison frames, taken at 30° altitude, were each divided into four segments, and a 20-star reduction was made on corresponding known stars in each section. The residuals from the least-squares fit of measured coordinates to standard coordinates showed no evidence of distortion. In several cases, the sky areas photographed with the window in place showed lower residuals, and the differences in reduced positions were well within the standard error for photoreduced observations.

The corrector-cell window is a plate of BK-7 glass ground to a flatness of 10λ and parallel to 10λ. The window protects the first element of the corrector cell from atmospheric pollutants and mishandling. It can be cleaned regularly without deterioration.

Laser Development Program. The factory acceptance testing of the first laser transmitter system is nearly completed, and fabrication of the second and third laser transmitter systems has begun.

A design review of the semiautomatic static-pointing pedestal was held. The first pedestal has been fabricated and assembled, and preliminary testing has begun. The second and third units have been fabricated and are almost completely assembled.

The major portion of the test equipment needed to operate the laser units has been procured.

Three complete ranging and data-recording electronic systems have been finished. Work is going on to reorganize the computer program to handle the new data printout format that this system provides. The new programing unit is being developed to control the complete observation cycle of the laser directly from computer punched tapes.

The new digital control features of the data-recording system permit an increase in the number of observation points available in each satellite pass. To take advantage of this capability, design work has been initiated to automate fully all laser-system operations, including those at Mt. Hopkins and Greece.

Some of the spare parts for the ranging and data-recording electronic system have been fabricated and procured.

The Agassiz Station was selected for field testing and system integration of the three new laser units. Site preparation is nearly complete. Construction of the ranging-laser shelter is almost finished.

The first laser unit should be received at SAO in February 1970 and is expected to be integrated with the data-recording electronics and installed at the Agassiz site for field testing by the following month.

Moonwatch

There are 145 Moonwatch stations that have registered site numbers and 30 additional stations that, though not available for routine observing, may be called on for satellite reentry observations or other special observing assignments. In addition, cooperative arrangements have been made with several world-renowned astronomical and astrophysical observatories for securing specialized data from nonroutine space missions. In all, Moonwatch receives data from 28 countries.

Moonwatch continues to administer the Volunteer Flight Officer Network under an Air Force contract.* The Smithsonian VFON consultant and field office are at Denver, Colorado. Administrative and production facilities have headquarters at SAO Moonwatch, Cambridge. Currently, the VFON encompasses 116 airlines in 54 countries, flying more than 2.6 million unduplicated air miles.

*Supported by USAF Contract F05603-69-C-0270.

From 1 July to 31 December 1969, 15,976 satellite observations by Moonwatch teams were reported. These figures compare exceptionally well with previous 6-month observing totals, considering that only Ephemeris 6 predictions for 13 satellites were sent to observers. The Moonwatch look-angle ephemeris was discontinued because of budgetary restrictions.

In this reporting period, a select group of Moonwatch observers continued to make observations of an accuracy comparable to that of Baker-Nunn field-reduced observations.

Moonwatch observations of low-perigee satellites, for studies of the atmosphere, have been given added importance because of reduction of other satellite-observing facilities. Our observations continue at an accelerated rate, to fill the requirements of scientists.

Moonwatch teams recorded an impressive array of observational data during the Apollo 11 and 12 missions. Photographic and visual observations were made from the earth coast phase of the missions to injection near lunar orbit. The telescopic instruments used ranged from the conventional Moonwatch apogee to the 61-in. telescope of the Harvard Agassiz Observatory. Photographs and spectrograms were made of cryogenic and water-fuel ventings, and video tapes taken through a 36-in. telescope recorded 12 hr of the Apollo 12 mission, including both translunar and transearth coasts to ranges of 200,000 mi.

Predictions for 50 reentering satellites were calculated and sent to Moonwatch stations and VFON pilots having possible visibility.

In this period, the Chief of Moonwatch visited NASA Headquarters, Washington, D. C., to discuss the operation of Moonwatch for Apollo space missions. He also visited communications directors of Aeronautical Radio, Inc. (ARINC), in Annapolis, Maryland. They agreed to send real-time satellite-decay information to pilots in flight and immediately to transmit positive observation reports back to the Space Defense Center, Cheyenne Mountain, Colorado. This service will begin soon.

Special ephemerides have been prepared and tested for use in a program for observing satellites with extremely high eccentricities and high apogee. Initial results are promising. Testing and refining of observational techniques will continue.

Other Activities

STADAD continues to provide, on a noninterference (no out-of-pocket cost) basis, logistical and operational support for scientific and technical groups around the world, including our cooperating agencies. Some of the groups supported during this report period are the following:

1. Peabody Museum of Archaeology and Ethnology, Harvard University — cultural and historical research on a nomadic group in Ethiopia. Telegraphic communications and shipping support provided.

2. Optical Physics Laboratory, Air Force Cambridge Research Laboratory (AFCRL) — observations for determination of tropical atmospheric dust concentration. Photographic support provided with equipment supplied by AFCRL.

3. Smithsonian Institution Center for Short-Lived Phenomena — collection of information on short-lived events and its dissemination to the international scientific community. Telegraphic communications support provided.

4. Geophysical Observatory of Haile Selassie I University, Ethiopia — geophysical research. Mail and telegraphic communications support provided.

5. Paris Institut d'Astrophysique — airglow observations at various wavelengths at the magnetic equator. Site facilities provided at the Ethiopia station.

COMMUNICATIONS

During the Apollo 11 flight, 775 messages dealing strictly with the mission were handled in the SAO Communications Center. More teletype traffic passed through the Center during the 8-day period of the Apollo 11 mission than in any previous month. Each shift was augmented to assist in message handling and to minimize transmitting delays. The switchboard remained open 24 hr a day from liftoff until spashdown, with two telephone operators handling the flood of telephone calls concerning the mission.

Because of the reduction of our staff, teletype and telephone traffic during the Apollo 12 flight was reduced. The cuts were made primarily in Transient Lunar Phenomena* message traffic and in no way affected our normal tracking support of the mission.

Under a cooperative program the SAO Communications Center has weekly been sending orbital elements for six satellites to the CNES.

The transmission of NORAD bulletins, NASA equatorial crossings, and SAO orbital elements to outside scientific groups has been discontinued in order that we maintain an operations level commensurate with our present staff and current budget limitations. The removal of one teletype circuit and three pieces of equipment has also been effected, thus reducing our rental fees. We plan to remove an additional line and associated equipment early in 1970.

The Division has received special recognition and a commendation for error-free crypto-operation on the military circuit during the months of August, November, and December of this report. A like compliment was received from Goddard for discrepancy-free operation on the NASA network during the last three months of 1969.

*Supported under NASA Contract NAS 9-9537.

DATA PROCESSING

DATA SERVICES

Weekly predictions on a total of 25 satellites (Table 3) were supplied to the astrophysical observing stations and Moonwatch sites. Selections for tracking were made at the direct request of NASA by SAO's scientific staff to fulfill its research commitments under the Satellite-Tracking Program grant. Simultaneous predictions were generated for the Air Force Baker-Nunn sites.

Laser predictions were provided for three SAO stations: Maui, Hawaii; Mt. Hopkins, Arizona; and Dionysos, Greece. During three special periods of collocation with the Goddard laser and cooperative high-density tracking of Geos 1 and Geos 2, predictions were also provided for the Australian laser developed by the Weapons Research Establishment and the laser developed by Air Force Cambridge Research Laboratories at Hanscom Field, Bedford, Massachusetts.

Orbital elements, predictions, field- and precisely-reduced observations, and long-range forecasts were provided on request to the SAO scientists and the staffs of the Tokyo Astronomical Observatory, University of California, University of Texas, U. S. Coast and Geodetic Survey, Department of Defense, Langley Research Center, University of London, CNES in France, Weapons Research Laboratory in Australia, and Uttar Pradesh State Observatory, India.

Pageos and Geos 2 continue to be used in a cooperative observing program with the Royal Radar Establishment at Malvern, England, and the European network of stations.

Solar-flux, planetary-index, polar-motion, and precise-timing data were received, tabulated, and distributed to interested persons in the scientific community.

Films of an Apollo 12 lox dump and an Apollo 12 waste-water dump are being analyzed.

PHOTOREDUCTION DIVISION

The film control section received and cataloged 17, 720 films from Smithsonian stations and three from Air Force stations.

A total of 4, 539 precise reductions of satellite positions were completed for this 6-month period, which brings the total of all reductions to 231, 169. Table 4 gives a breakdown of the satellite reductions during this period.

PROGRAMING DIVISION

The Programing Division is responsible for the development of computer programs for all phases of the Satellite-Tracking Program, for the maintenance of existing computer programs, and for development work in applied mathematics required to achieve these objectives. The computer programs now use almost exclusively a Control Data 6400 located at 185 Alewife Brook Parkway.

Programs in Development

SCROGE — Development of SCROGE has included the addition of blocked binary I/O to reduce peripheral processor time. The latest version also includes an update of the time base to the 1970s for the outgoing prediction messages. Routines for the reading and conversion of 5- and 8-level teletypewriter paper-tape code have been written for the processing of data from stations.

Table 4. Reductions completed 1 July to 31 December 1969

Object	Period	Program		No of Images
Geos 1	March - December 1967	Geometric Geodesy		1094
Geos 1	January - July 1968	"	"	1213
Miscellaneous Simobs	April - December 1968	"	"	2118
Explorer 38	January 1969	"	"	114
		Total		4539

GRIPE — Several new programs have been added to GRIPE for the analysis of geodetic data. Currently, a GRIPE program library using UPDATE is being written.

DOI — Several changes in the routines ZONLPT, ZONAL, COMEXP, and SLOI have been added to effect a modification in the computation of $\dot{\omega}$. These corrections affect only runs requesting MAR and not requesting SLOI. Two problems that caused DOI occasionally and arbitrarily to abort have been corrected, and the modifications have been incorporated into the current version. Work continues on the DOI write-up.

Ephemeris Package — Involvement with the ephemeris package is mainly maintenance and minor additions and corrections.

Laser Prediction — Extensive internal changes to the laser prediction program have been made so that it runs more efficiently when several satellites are handled in the same run. Other programs for processing laser observations have also been modified to meet changing specifications.

Geopotential — This project for the development of alternate functions for geopotential expansions has been completed and the results are now being published (see Special Report Number 294).

SPASM — SPASM has been used as the principal tool in investigating Kozai's second-order oblateness perturbation results.

Star Catalog — The Photoreduction Star Catalog has been updated for the next 2 years.

WOBBLE — This program was written to determine polar motion from simultaneous direction observations.

FLECT — This new program computes the deflection from the vertical of points on the earth with respect to the standard geoid.

MATCH — MATCH, another recent program, was prepared to update periodically the Yale deck of astronomical objects with contact observation data.

EDITORIAL AND PUBLICATIONS

EDITORIAL AND PUBLICATIONS

Listed below are recent papers and Special Reports that relate to results from the Satellite-Tracking Program.

Barker, J. I., and Grossi, M. D., "OV4-1 Dual Satellite Experiment." In Summaries of Papers (Proceedings of the Symposium on the Application of Atmospheric Studies to Satellite Transmissions, Boston, Massachusetts, September 1969), AFCRL, Bedford, Massachusetts, pp. 116-119, 1969.

Gaposchkin, E. M., and Lambeck, K., "New Geodetic Parameters for a Standard Earth." Presented at the Western National Meeting of the American Geophysical Union, San Francisco, California, December 1969.

Hall, N. M., and Cherniack, J. R., "Smithsonian Package for Algebra and Symbolic Mathematics." Smithsonian Astrophys. Obs. Spec. Rep. No. 291, 49 pp., 1969.

Hamid, S. E., "Second-Order Planetary Theory. Part I: Outline of the Method." Smithsonian Astrophys. Obs. Spec. Rep. No. 302, 83 pp., 1969.

__________, "Second-Order Planetary Theory: Outline of the Method." Presented at the 130th AAS Meeting, Albany, New York, August 1969.

Jacchia, L. G., "The Neutral Atmosphere above 200 km." In Space Research IX, ed. by K. S. W. Champion, P. A. Smith, and R. L. Smith-Rose, North-Holland Publ. Co., Amsterdam, Holland, pp. 478-486, 1969.

__________, "Atmospheric Density Variations during Solar Maximum and Minimum." In Solar-Terrestrial Physics: Terrestrial Aspects (Annals of IQSY, vol. 5), ed. by A. C. Stickland, MIT Press, Cambridge, Massachusetts, pp. 323-339, 1969.

Lambeck, K., "Position Determination from Simultaneous Observations of Artificial Satellites: an Optimization of Parameters." Bull. Géod., no. 92, pp. 155-167, 1969.

Lundquist, C., et al., "New Geodetic Parameters for a Standard Earth." _Smithsonian Astrophys. Obs. Spec. Rep. No_. 305, 1969.

Mathur, N. C., "A Pseudodynamic Programming Technique for the Design of Correlator Supersynthesis Arrays." _Radio Sci_., vol. 4, pp. 235-243, 1969.

__________, "Ray-Tracing Analysis of Ionospheric and Tropospheric Effects on Interferometric Distance Determination." Presented at the Western National Meeting of the American Geophysical Union, San Francisco, California, December 1969.

Miller, B., prepared, "Satellite Orbital Data, "No. O-18. _Smithsonian Astrophys. Obs. Spec. Rep. No._ 287, 103 pp., 1968.

__________, prepared, "Satellite Orbital Data," No. O-19. _Smithsonian Astrophys. Obs. Spec. Rep. No._ 289, 96 pp., 1968.

__________, prepared, "Satellite Orbital Data," No. E-8. _Smithsonian Astrophys. Obs. Spec. Rep. No._ 290, 27 pp., 1968.

__________, prepared, "Catalog of Precisely Reduced Observations," No. P-18. _Smithsonian Astrophys. Obs. Spec. Rep. No._ 296, 196 pp., 1969.